Decomposing economic growth decompositions

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Decomposing Economic Growth Decompositions

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Abstract This paper deals with an application of input-output analysis that regularly appears in the literature without consideration of its limitations. Structural decomposition analysis (SDA) of economic growth almost always tells the analyst that the growth of final demand is by far the most important component in explaining economic growth. SDA, however, only looks at demand side explanations of growth, while ignoring the supply side, which is especially a problem when analysing longer run economic growth. This paper compares SDA with shift-and-share analysis and growth accounting, two other economic growth decomposition analyses, in order to understand the properties and limitations of all three methods and to propose an econometric combination as a remedy.

Keywords Input-output analysis, structural decomposition analysis, shift-and-share analysis, growth accounting

JEL-codes C18, C67, O40, R11

1. Introduction

Input-output (IO) analysis is built upon four basic models: two quantity models and two accompanying price models (see Oosterhaven 2019, for an extensive discussion and comparison). Only the two quantity models are potentially suited to analyse economic growth. The less well known supply-driven quantity model (Ghosh 1958) has been heavily criticized because of its assumption of full substitutability of all inputs, which implies that cars may drive without energy and factories may work without labour. Probably for this reason it has never been used to analyse economic growth. The much better known demand-driven quantity model (Leontief 1941) has been used extensively for this purpose.

In the basic version of this model, exogenous final demand for products of industry *i* ($y_i \in \mathbf{y}$) and intermediate demand for products *i* by all industries *j* ($\sum_j z_{ij} \in \mathbf{Z}\,\mathbf{i}$) together determine the supply of output by industry *i* ($x_i \in \mathbf{x} = \mathbf{Z}\,\mathbf{i} + \mathbf{y}$). Endogenous intermediate demand for products *i* by industry *j* is, without economies of scale, linearly determined by the size of industry *j*´s total output ($z_{ij} = a_{ij} x_j \in \mathbf{Z}\,\mathbf{i} = \mathbf{A}\,\mathbf{x}$), which implies full complementarity of all inputs. The solution of the basic Leontief model reads as follows:

$$x_i = \sum_j l_{ij} y_j \in \mathbf{x} = \mathbf{L}\mathbf{y} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{1}$$

in which l_{ij} are the elements of the so-called Leontief-inverse $(\mathbf{I} - \mathbf{A})^{-1}$, indicating the demand-driven direct plus indirect impact on total output of industry *i* of any change in exogenous final demand for products from industry *j*.

In the analysis of economic growth all kind of extensions of (1) have been used to decompose the growth of total output or value added or employment into the growth of various components of exogenous final demand and various changes of the specific IO model´s coefficients. This important field of IO applications dates back to Leontief (1941). Since then, thousands of such structural decomposition analyses (SDAs) have been done (see Miller and Blair 2009, ch. 13, for a recent overview).[1] In their extensive evaluation of SDA, Rose and Cassler (1996) emphasise the similarities between SDA, shift-and-share analysis (SSA) and growth accounting. The communality is that all three approaches decompose a growth equation into its constituent parts.

Here, we aim at a critical evaluation of all three decomposition methods. For that purpose we will emphasise the clarifying, fundamental differences between them. We conclude that an econometric estimation of extended growth accounting equations offers the best approach to explaining, especially, long run economic growth. Such an econometric estimation should exclude the residual, total factor productivity component of growth accounting, whereas it should include other explanatory variables, such as the individual components from a SSA and/or a SDA.

2. Shift-and-share analysis of regional economic growth

We start our overview with the decomposition technique that has no theoretical foundation, except for the notion that the local mix of industries is important in explaining the difference between a region/nation and some other geographical unit with which one wants to compare that region/nation. Hence, we first discuss *shift-and-share analysis* (first used by Creamer 1942, and popularized by E.S. Dunn in Perloff et al. 1960). Its most simple application decomposes the following identity:

$$v^r - v^n \equiv \sum_i s_i^r v_i^r - \sum_i s_i^n v_i^n \text{, with } \sum_i s_i^r = \sum_i s_i^n = 1 \text{,} \qquad (2)$$

where v = variable of interest (e.g. total GDP growth, total job growth, average wage level, total energy use, total CO_2 emissions) for some unit r (e.g. region) that is to be compared with some norm n (e.g. nation), and that is aggregated over some index i (e.g. industry), with $s_i^r \equiv v_i^r / \sum_i v_i^r$ = share of i in r as regards v, and s_i^n = defined analogously.[2] From (2) it follows that SSA may be used to analyse a multitude of issues.[3] Here we only discuss its oldest and most frequently used application to economic growth.

Table 1 shows the five ways in which (2) may be decomposed. It can easily be verified that all five decompositions have the desired property of its components being mutually exclusive and exhaustive. The first decomposition in Table 1 shows the classical SSA of regional growth v^r into its *share* in national growth v^n, plus a *proportional shift* due to a different industry mix $\sum_i (s_i^r - s_i^n) v_i^r$, plus a residual *differential shift* $\sum_i s_i^n (v_i^r - v_i^n)$. The latter gives an indication of the impact of regional competitiveness, as it measures whether the weighted average regional industry grows faster of slower than its national counterpart (the *italics* indicate the origin of the term *shift-and-share*). Capello (2007) further clarifies that the industry mix component is primarily related to demand-side growth factors, whereas the residual competitiveness component is primarily related to supply-side growth factors.

Both components may be measured, respectively weighted, differently, as is evident from a comparison of the first and second decomposition in Table 1. Taking the average of the first two

[1] On 10 December 2019, the combination of "structural decomposition analysis" and "input-output" combined scored about 4,100 hits on Google Scholar.
[2] Note that the definition of the share may need to be adapted to the definition of the variable, as will be the case when decomposing a double ratio, such as labour productivity growth (see Oosterhaven and Broersma 2007).
[3] In international economics, e.g. with v = export growth, r = some country, n = all of the world, and i = products, shift-and-share analysis is known as *constant market share analysis* (see Jepma 1986, for an overview and several applications)

decompositions delivers the third decomposition. Taking a simple average is the typical solution of SDA to the problem of choosing between IO model components measured in base year terms and those measured in end year terms (Skolka 1989). In shift-and-share analyses, however, taking the average is not the preferred choice.

When the research interest is in comparing different regions/nations, each component needs to be measured/weighted in the same way for all regions/nations. This argument makes the first three and, especially, the fourth decomposition in Table 1 inacceptable for interregional/international comparisons. Luckily, there is a fifth decomposition that measures/weighs, the industry mix component as well as the competitiveness component in the same way such that they can be compared between regions/nations. To reach this result, a third component has to be added (see the fifth decomposition in Table 1).

This *interacting differences component* is theoretically interesting on its own account, as it measures whether the industries in which a region/nation is specialized have a high or low score on the variable of interest. This third component thus measures the impact of regional specialization, i.e. it measures so-called *localization economies* (see Oosterhaven and Broersma, 2008, for the difference with cluster, urbanisation and agglomeration economies). For this additional reason, the fifth decomposition should even be considered to represent the preferred decomposition when the research interest only regards a single region/nation.[4]

Table 1. Possible shift-and-share decompositions of $v^r - v^n$

No.	Industry mix component, with: regional growth rates	Industry mix component, with: national growth rates	Competitiveness component, with: regional industry shares	Competitiveness component, with: national industry shares	Interacting differences (specialization) component
	$\sum_i (s_i^r - s_i^n) v_i^r$	$\sum_i (s_i^r - s_i^n) v_i^n$	$\sum_i s_i^r (v_i^r - v_i^n)$	$\sum_i s_i^n (v_i^r - v_i^n)$	$\sum_i (s_i^r - s_i^n)(v_i^r - v_i^n)$
1.	+			+	
2.		+	+		
3.*	½	½	½	½	
4.	+		+		-
5.		+		+	+

* This decomposition results from taking the average of decomposition 1 and 2 as well as that of 4 and 5.
Source. Oosterhaven and van Loon (1979)

In case of regional wage differences (Oosterhaven and van Loon 1979) and regional labour productivity differences (Oosterhaven and Broersma 2007) specialization clearly pays off, in the sense that industries in which a region is specialized have higher levels of labour productivity and pay higher wages than their national counterparts, indicating positive localization economies. In case of employment growth and value added growth, however, the *specialization component* proved to be negative for all Dutch regions, which was interpreted as representing diminishing returns to these positive localization economies. The same result was found for earlier periods, for different regional and different sectoral classifications (WWR 1980, Oosterhaven and Stol 1985).

The industry mix component proved to exhibit a stable regional pattern over eight periods between 1951 and 1983, with a slowly diminishing importance, starting with "explaining" a halve and ending with "explaining" only a quarter of the regional differences in job growth. The residual competitiveness component, on the other hand, gained importance, but with an unstable pattern with even changing signs between subperiods. The changing of signs appeared to be related to changes in national economic

[4] This decomposition also proved to be superior from an *empirical* point of view in case of regional wage differences in The Netherlands, as its three components were mutually uncorrelated, as opposed to the components of the other decompositions (Oosterhaven and van Loon 1979).

growth. Core regions showed a relative slow-down of their residual growth during periods of national growth, probably due to congestion and supply shortages, whereas peripheral regions catched up part of their economic arrears during periods of national growth, probably due to picking up part of the core regions´ choked off growth.

The most mentioned objections against the above summarized type of SSAs of regional growth are (1) their lack of a theoretical foundation (Richardson 1978), and (2) the impossibility to determine the statistical significance of its components (Stillwell 1969, Chalmers and Beckhelm 1976, Stevens and Moore 1980). Besides, it was noted that (3) the industry mix component is sensitive to sectoral aggregation, being more important at lower levels of aggregation, while (4) its size is underestimated due to interindustry interdependences (Mackay 1968).

The lack of a theoretical foundation, however, may be turned into an advantage if the unstable residual component is dropped, while the industry mix and the specialization component are used as regular, but composite variables in an econometric estimation of the LHS of (2). This, in fact, simultaneously solves the second objection, as it provides a measure of the statistical significance of these two components in explaining the LHS of (1) (see Graham and Spence 1998, and Broersma and Oosterhaven 2009, for applications of this approach).

3. Structural decomposition analyses of national and international growth

Next, consider the oldest and most simple IO *structural decomposition analysis* (SDA), which splits up output growth by industry:

$$\Delta\mathbf{x} \equiv \mathbf{x}_1 - \mathbf{x}_0 = (\mathbf{I} - \mathbf{A}_1)^{-1}\mathbf{y}_1 - (\mathbf{I} - \mathbf{A}_0)^{-1}\mathbf{y}_0 = \mathbf{L}_1\mathbf{y}_1 - \mathbf{L}_0\mathbf{y}_0\,, \tag{3}$$

wherein: $\Delta x_i \in \Delta\mathbf{x}$ is a column with the absolute growth of endogenous output by industry *i* from period 0 to period 1, $a_{ij} = z_{ij} / x_j \in \mathbf{A}$ is a matrix of input coefficients, indicating the use of intermediate inputs from industry *i* per unit of output of industry *j*, $y_i \in \mathbf{y}$ is a column with the levels of exogenous final demand for the outputs of industry *i*, and $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief-inverse.

An SDA of (3) represents a *comparative static analysis* that sequentially looks at the impact on the variable of interest of changes in each set of parameters, holding the other sets of parameters constant. Note that SDA may be used to decompose any first order difference in a matrix equation (such as the difference between national and regional embodied CO_2 emissions, or the growth of energy use, see Rose and Chen 1991, for an extensive SDA of the latter). However, here we only discuss its most common application, namely, to long run economic growth.

Just like the decomposition of (2), there are five comparable decompositions of (3) (see Table 2). Again their components are mutually exclusive and exhaustive. Skolka (1989) presents four of them, while Decomposition 4 is added by Oosterhaven and van der Linden (1997). In choosing between the first two decompositions, Skolka (1989) refers to the circularity principle (UN 1975), which leads to a preference for combining Laspeyres volume indexes with Paasche price indices. Skolka nor Miller and Blair (2009), however, see any such preference in case of SDA, which is why they prefer the third decomposition. This choice neglects the *interaction component* $\Delta\mathbf{L}\,\Delta\mathbf{y}$ in the alternative, also logical fifth decomposition in Table 2. However, this is not a real loss, as the interaction component is empirically found to be rather small (Uno 1989), while it is theoretically considered to have no clear economic interpretation (Skolka 1989, Miller and Blair 2009). Here SDA clearly deviates from SSA.[5]

Table 2. Possible structural IO decompositions of industry output growth $\Delta\mathbf{x}$

	Leontief-inverse change, with:		Final demand change, with:		Interaction component
	base year **y**	end year **y**	base year **L**	end year **L**	
No.	$\Delta\mathbf{L}\,\mathbf{y}_0$	$\Delta\mathbf{L}\,\mathbf{y}_1$	$\mathbf{L}_0\,\Delta\mathbf{y}$	$\mathbf{L}_1\,\Delta\mathbf{y}$	$\Delta\mathbf{L}\,\Delta\mathbf{y}$
1.	+			+	
2.		+	+		
3.*	½	½	½	½	
4.		+		+	-
5.	+		+		+

* This decomposition results from taking the average of decomposition 1 and 2 as well as of 4 and 5.

Departing from the most simple IO model used in (3), many, more sophisticated variants with an increasing number of components have been developed (see Rose and Casler 1996, and Miller and Blair 2009, for overviews). To increase the understanding of the type of outcomes that a SDA may generate, we showcase the decomposition of value added growth in the EU by Oosterhaven and van der Linden (1997), as it includes most of the individual components proposed in the literature. They use an *interregional IO model* with *I* industries, *R* countries and *Q* types of final demand (i.e. household consumption, capital investments, government expenditures and exports to non-EU countries). Specific to their approach is that each of the intercountry intermediate input coefficients a_{ij}^{rs} and each of the intercountry final demand input coefficients b_{iq}^{rs} (often called bridge coefficients) is split up into a technical or preference coefficient and a trade origin ratio (in all cases the first index indicates the origin and the second index the destination of the flow at hand).

The solution of their interregional IO model reads as follows:

$$\mathbf{v} = \hat{\mathbf{c}}\;\mathbf{L}\mathbf{B}\;\mathbf{y} = \hat{\mathbf{c}}\;(\mathbf{I} - \mathbf{M}^a \otimes \mathbf{A})^{-1}(\mathbf{M}^f \otimes \mathbf{F})\;\mathbf{y}\;. \tag{4}$$

In (4), $\otimes$ = the Hadamar product (i.e. cell-by-cell matrix multiplication), and going backwards along the causal chain of their model: $y_{\cdot q}^{\cdot s} = \sum_i^r y_{iq}^{rs} \in \mathbf{y}$ = a *QR* column with macro-economic levels of final demand of type *q* per country *s*, $f_{iq}^{\cdot s} \in \mathbf{F}$ = an *IR* x *QR* block matrix, with *R* mutually identical *I* x *QR* matrices with final demand *preference coefficients*, indicating the total use of product *i* from all over the world per unit of final demand of type *q* in country s, $m_{iq}^{rs} \in \mathbf{M}^f$ = an *IR* x *QR* matrix with cell-specific trade origin ratios, indicating which fraction of that final demand originates from country *r*, $a_{ij}^{\cdot s} \in \mathbf{A}$ = an *IR* x *IR* block matrix, with *R* mutually identical *I* x *IR* matrices with *technical coefficients*, indicating the total use of product *i* from all over the world per unit of output of industry *j* in country *s*, $m_{ij}^{rs} \in \mathbf{M}^a$ = an *IR* x *IR* matrix with cell-specific trade origin ratios, indicating which fraction of that intermediate

[5] Elements of SSA may be integrated into an SDA, as suggested by Lahr and Dietzenbacher (2017). They show that in case of a regional SDA – with the added data from two national IOTs – both $\Delta\mathbf{y}$ and $\Delta\mathbf{L}$ may be split up further into changes in the levels and structures of the regional and national **y** and **L**. Such a further split up of the decompositions of Table 2, however, does not change their demand-driven nature nor their other properties, to be discussed next.

demand originates from country r, $\hat{\mathbf{c}}$ = an IR x IR diagonal matrix with gross value added coefficients on its diagonal, and $\mathbf{v}$ = an IR column with gross value added per industry, per country.

The comparative static decomposition of the *changes in the last part of (4)* is laborious, but straightforward, except for the decomposition of the change in the intercountry Leontief-inverse $\mathbf{L}$ into changes in the technical coefficients $\mathbf{A}$ and changes in the intermediate trade origin ratios $\mathbf{M}^a$, which reads as:

$$\Delta\mathbf{L} = \mathbf{L}_1\Delta(\mathbf{M}^a \otimes \mathbf{A})\mathbf{L}_0 = 0.5\mathbf{L}_1\Delta(\mathbf{M}_0^a + \mathbf{M}_1^a) \otimes \Delta\mathbf{A}\,\mathbf{L}_0 + 0.5\mathbf{L}_1\Delta\mathbf{M}^a \otimes (\mathbf{A}_0 + \mathbf{A}_1)\mathbf{L}_0 . \tag{5}$$

The crucial first equality of (5) may be proven by pre-multiplication and post-multiplication of the first two terms of (5) with $(\mathbf{I} - \mathbf{A}_1 \otimes \mathbf{M}_1^a)$ and $(\mathbf{I} - \mathbf{A}_0 \otimes \mathbf{M}_0^a)$, respectively. The last term of (5) gives the average of the two possible decompositions of the change in the Leontief-inverse without an interaction term.

The overall decomposition of the change in the last part of (4) subsequently requires three steps:

1. The standard decomposition is applied to the four terms of the first part of (4). That is done in such a way that the variable with the Δ moves from the left to the right for the first decomposition, whereas it moves from the right to the left for the second decomposition, after which the *average* of these two, so-called *polar decompositions* is taken. This delivers the component for $\Delta\hat{\mathbf{c}}$ in (6a) and that for $\Delta\mathbf{y}$ in (6f), where each of the two sets of weights nicely shows the polar nature of the two decompositions that are averaged.
2. Next, the last part of (5) is substituted into $0.50(\hat{\mathbf{c}}_0\Delta\mathbf{L}\,\mathbf{B}_1\mathbf{y}_1 + \hat{\mathbf{c}}_1\Delta\mathbf{L}\,\mathbf{B}_0\mathbf{y}_0)$, the component for the change in the Leontief-inverse derived as part of Step 1. This gives the component for $\Delta\mathbf{M}^a$ in (6b) and that for $\Delta\mathbf{A}$ in (6c).
3. Finally, $0.50(\hat{\mathbf{c}}_0\mathbf{L}_0\Delta\mathbf{B}\,\mathbf{y}_1 + \hat{\mathbf{c}}_1\mathbf{L}_1\Delta\mathbf{B}\,\mathbf{y}_0)$, the component for the change in the matrix with final demand input or bridge coefficients derived as part of Step 1, is subdivided into a component for $\Delta\mathbf{M}^f$ in (6d) and one for $\Delta\mathbf{F}$ in (6e).

These three steps deliver the following decomposition of the *changes in the last part of (4)*:

$$\Delta\mathbf{v} = 0.50\Delta\hat{\mathbf{c}}\,(\mathbf{L}_0\mathbf{B}_0\mathbf{y}_0 + \mathbf{L}_1\mathbf{B}_1\mathbf{y}_1) + \tag{6a}$$

$$0.25\Big[\hat{\mathbf{c}}_0\,\mathbf{L}_1\,\Delta\mathbf{M}^a \otimes (\mathbf{A}_0 + \mathbf{A}_1)\mathbf{L}_0\mathbf{B}_1\mathbf{y}_1 + \hat{\mathbf{c}}_1\mathbf{L}_1\,\Delta\mathbf{M}^a \otimes (\mathbf{A}_0 + \mathbf{A}_1)\mathbf{L}_0\mathbf{B}_0\mathbf{y}_0\Big] + \tag{6b}$$

$$0.25\Big[\hat{\mathbf{c}}_0\,\mathbf{L}_1(\mathbf{M}_0^a + \mathbf{M}_1^a) \otimes \Delta\mathbf{A}\,\mathbf{L}_0\mathbf{B}_1\mathbf{y}_1 + \hat{\mathbf{c}}_1\mathbf{L}_1(\mathbf{M}_0^a + \mathbf{M}_1^a) \otimes \Delta\mathbf{A}\,\mathbf{L}_0\mathbf{B}_0\mathbf{y}_0\Big] + \tag{6c}$$

$$0.25\Big[\hat{\mathbf{c}}_0\,\mathbf{L}_0\,\Delta\mathbf{M}^f \otimes (\mathbf{F}_0 + \mathbf{F}_1)\mathbf{y}_1 + \hat{\mathbf{c}}_1\,\mathbf{L}_1\,\Delta\mathbf{M}^f \otimes (\mathbf{F}_0 + \mathbf{F}_1)\mathbf{y}_0\Big] + \tag{6d}$$

$$0.25\Big[\hat{\mathbf{c}}_0\,\mathbf{L}_0(\mathbf{M}_0^f + \mathbf{M}_1^f) \otimes \Delta\mathbf{F}\,\mathbf{y}_1 + \hat{\mathbf{c}}_1\,\mathbf{L}_1(\mathbf{M}_0^f + \mathbf{M}_1^f) \otimes \Delta\mathbf{F}\,\mathbf{y}_0\Big] + \tag{6e}$$

$$0.50(\hat{\mathbf{c}}_0\mathbf{L}_0\mathbf{B}_0 + \hat{\mathbf{c}}_1\mathbf{L}_1\mathbf{B}_1)\Delta\mathbf{y} . \tag{6f}$$

The above average of two polar decompositions, however, represents only one of many possible decompositions. Dietzenbacher and Los (1998), also ignoring interaction components, show that the number of possible basic decompositions equals the faculty of the number of components (n). They, luckily, also show that decompositions like that of (6), being the average of two polar decompositions, have empirical outcomes that are very close to the average of all n! possible basic decompositions.

When used to analyse *economic growth*, SDA is usually applied to longer time periods, and practically always reports that changes in the level of final demand constitute by far the most important component. Feldman et al. (1987), following the seminal study of Anne Carter (1970) with more recent and more detailed IO data, e.g. analyse a decomposition of the growth of $\mathbf{x} = \mathbf{L}\mathbf{B}\mathbf{y}$ for the USA over the period 1963-1978. They find that changes in **y** are far more important than changes in either **L** or **B**, for some 80% of the 400 American industries distinguished. Coefficient changes were only important in case of the fastest and the slowest growing industries (see Fujimagari 1989, for very comparable results for Canada). From those outcomes, they conclude that the best economic growth policy is a good macro-economic policy. The question is whether that conclusion is justified.

Applying (6) to their EU intercounty input-output tables (IOTs) for 1975-1985, Oosterhaven and van der Linden (1997) also report final demand growth, especially of household consumption, to be by far the most important component for all eight countries and for almost all of the 25 industries distinguished. The combined effect of the five types of coefficient changes in (6) proved to be rather small and predominantly negative, which is mainly caused by a systematic decline in value added coefficients in (6a), indicating more roundabout production processes with longer supply chains incorporating more non-EU value added. At the industry level for individual countries, however, they do find larger impacts of different types of coefficient changes, which leads them to conclude that sector policies may be more important for economic growth than indicated by Feldman et al. (1978), also because the economically much more open EU countries have less scope for macro-economic policies than the economically more closed USA. Again the question is whether that conclusion is justified.

Finally, we look at SDA results for the third large international trading unit, i.e. China. Andreosso-O´Callaghan and Yue (2002) also find for China that the growth of total final demand, and specifically the export growth of ´high-tech´ industries, constitutes by far the largest contribution to its output growth for 1987-1997. They, however, do not make a distinction between ordinary exports and *processing exports* that add only limited amounts of domestic value added to mainly imported materials. This distinction is important as processing exports, in contrast to ordinary exports, hardly have any indirect impacts on domestic value added. Pei et al. (2012), using Chinese IOTs with both kinds of exports separated for 2002-2007, conclude that the contribution of exports to domestic value added is over-estimated with 32% if the two types of exports are aggregated, while the contribution of exports to the value added of the ´high-tech´ telecommunication industry is even over-estimated with 63%. Still, they too report that the growth of domestic final demand "explains" as much as 70% of Chinese GDP growth, whereas changes in coefficients "explain" only *minus* 5%. The remainder of about 35% is "explained" by the growth of both types of exports.

In the last paragraph above, the word *explained* has been put between quotation marks. The phrase "deterministically attributed to" would have been more correct, be it more cumbersome. As opposed to SSA, SDA is seldom criticised. The main critique (Rose and Casler 1996, Dietzenbacher and Los 1998, Miller and Blair 2009) regards (1) the non-uniqueness of each decomposition and (2) the weak theoretical foundation for taking averages. However, just like SSA, SDA also needs to be criticised because of (3) the impossibility to determine the statistical significance of its components and (4) its sensitivity to sectoral aggregation. As opposed to SSA, however, SDA does have a theoretical foundation, namely the demand-driven IO quantity model (Leontief 1941). In case of SSA the lack of a theoretical foundation and the related presence of a residual component can be turned into an advantage that solves the problem of establishing the statistical significance of its non-residual components.

In contrast, having a theoretical foundation may easily be considered to represent the weakest aspect of SDA, for two reasons. First, as opposed to SSA, and precisely because of its theoretical foundation, SDA does not have a residual component that, by dropping it in an econometric estimation, may be used to establish the statistical significance of the other components. Second, depending upon the type of application, the assumptions of the underlying demand-driven IO quantity model may represent a major problem.

This is at least the case in the largest area of SDA applications, i.e. the decomposition of industry output growth and GDP growth. In case of short run, year-to-year changes, especially when the economy operates below full capacity, the Leontief model more or less adequately captures the, in the short run dominant *demand-side* causes of economic growth and decline (see further Oosterhaven 2019).

4. The other, supply side of the coin: growth accounting

In case of the longer run of five or more years, however, SDA unjustly ignores the impact of changes on the *supply-side* of the economy, such as the growth of labour supply, the growth of the capital stock and technological change. In this context, the third decomposition approach, *growth accounting* represents the almost complete opposite of SDA in that it ignores the demand side and decomposes the growth of industry output and GDP exclusively into the contributions of supply side components (see Kendrick 1961, for a first account, and Jorgenson and Griliches 1967, for a first seminal contribution).

Growth accounting may be founded in production theory (Diewert 1976, Caves et al. 1982). Using a translog function of production possibility frontiers, and assuming competitive factor markets, full input utilization and constant returns to scale, the relative growth of *multi-factor productivity* of industry *j* ($\Delta \ln A_j$) may be estimated as the *residual* of the relative growth of the total output of industry *j* ($\Delta \ln x_j$) and the weighted relative growth of its use of capital (k_j), labour (l_j) and intermediate inputs (z_j) (Timmer et al. 2010, ch. 2):

$$\Delta \ln A_j = \Delta \ln x_j - w_{kj}\Delta \ln k_j - w_{lj}\Delta \ln l_j - w_{zj}\Delta \ln z_j \tag{7a}$$

$$\text{with } w_{kj} = p_{kj}k_j / p_j x_j \,,\;\; w_{lj} = p_{lj}l_j / p_j x_j \,,\; w_{zj} = p_{zj}z_j / p_j x_j \,, \text{and } w_{kj} + w_{lj} + w_{zj} = 1 \tag{7b}$$

wherein: A = level of multi-factor productivity, w = respective weights and p = respective prices.

In empirical applications, capital, labour and total intermediate inputs are often split up further, mostly by means of data from IOTs or supply-use tables (SUTs), while the weights are mostly calculated as the average of the begin year weight and the end year weight, as in the well-known and often used EU KLEMS database (see Timmer et al. 2010, ch.3). Note that (7) may also be calculated directly with two IOTs or two SUTs, in which case the weights will equal the primary input coefficients and the intermediate input coefficients by industry averaged over the begin year and the end year of the analysis (see Jorgenson, Gollop and Fraumenti 1987).

The primary field of the application of growth accounting is not the analysis of industry output and GDP growth, but that of residual productivity growth. Comparing the USA and Europe, van Ark et al. (2008, see also Timmer et al. 2010) show that Europe was catching up in labour productivity until about 1995, after which it experienced a slowdown, whereas the USA significantly accelerated its productivity growth, at least until 2006. At the detailed industry level, traditional manufacturing no longer acted as the productivity engine of Europe, probably due to exhausted catching-up possibilities, while Europe´s industries lagged in participating in the new knowledge economy, lagged in investing in information and communication technology, and lagged in keeping up their multi-factor productivity growth. These differences, especially, led to an increasing gap in the productivity of European trade and business services, of course, with variations from industry to industry and from country to country.

Also in the case of China, growth accounting tells a story that is completely different from that of SDA, where growth of final demand is the dominant "explanation". Wu (2016) decomposes China´s 9.16% annual GDP growth over the period 1980-2000 into 6.61% due to the growth of capital, 1.32% due to the growth of labour and 1.24% due to total factor productivity (TFP) growth. Of the 1.32% due to labour growth, 75% is attributed to quality improvement and 25% to the growth of hours worked. Of the 1.24% due to TFP growth, 70% is attributed to TFP growth at the industry level and 30% to the reallocation of capital and labour between industries. Differences in the contribution of the individual industries to these aggregate results are mainly explained by industry differences in market structures and policy interventions, running from being essentially centrally planned to being open to world competition.

Comparable to SDA, the above type of growth accounting analyses also suffer from their deterministic nature. In both cases the statistical significance of the components cannot tested. The assumptions of the production function model (7) are simply believed in, just as IO people simply believe in their IO model, be it (3) or (4). In the case of growth accounting, solely by definition, demand does not play a role. Supply-side components dominate the story. However, looking at supply-side factors only is as one-sided as looking at demand-side factors only. The latter may be acceptable when analysing short run year-to-year changes in economic growth. Looking only at supply-side will be far more appropriate when analysing longer run economic growth.

4. Conclusion

However, in the case of growth accounting there is no reason to restrict the analysis to supply-side factors only. The reason is that growth accounting contains a residual component ($\Delta \ln A_j$), just like shift-and-share analysis (SSA). And comparable to SSA, dropping the residual growth component allows for an econometric estimation of $\Delta \ln x_j$. This simultaneously delivers an estimate of the statistical significance of the, in that case, estimated weights of the remaining components of (7). This econometric approach, furthermore, enables the analysist to estimate the real importance (if any) of demand-side factors in explaining shorter or longer run economic growth, namely by adding such factors as potential explanatory variables.

Hence, in our opinion, the best overall approach to analysing, especially, longer run economic growth is to start with growth accounting, but to *not* use the deterministic decomposition approach of (7), but an econometric explanation of $\Delta \ln x_j$ in order to let the data decide which factors are most important in explaining economic growth, instead of assuming to know the answer beforehand, as is done in all three deterministic decomposition analyses. In such an *econometric growth accounting analysis*, components from either a SSA and/or a SDA may and should be used fruitfully as providers of composite explanatory variables.

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